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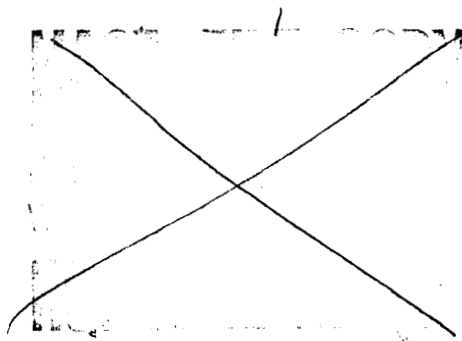
SUBJECT: To "G" or not to "G"

DATE: September 24, 1968

FROM: E. D. Marion

ABSTRACT

This memo discusses the various arguments for or against the use of artificial gravity in future manned space stations. Schedules and rough cost estimates are presented for various alternatives. Results indicate that the cheapest approach is to include artificial gravity capability in the spacecraft design.
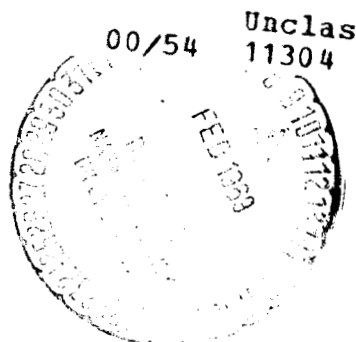
SUBJECT: To "G" Or Not to "G"
Case 710

DATE: September 24, 1968

FROM: E. D. Marion

MEMORANDUM FOR FILE

In the past few months there has been much discussion of the use of artificial g on long term spacecraft. I would like to summarize the major features of this discussion and add some thoughts which have evolved but remained undocumented until now.

Arguments

The basic question is whether or not long term space-craft should be spun to provide artificial gravity. Since we are soon to take the first steps toward such a long term station, the question has a flavor of immediacy about it. Clearly a station can be designed to provide artificial gravity or designed to work without it, but it will be very costly to switch from one to the other in mid-stream. The various arguments for and against the use of artificial gravity go something like this.

Biomedical Requirements

In general the medical community claims a lack of evidence that man can function properly in abaria for longer than 14 days. Despite this lack of evidence opinion seems to run toward the idea that man _can_ adapt himself to prolonged abaria, but this is opinion, nothing more. In other words it is possible that man can't physiologically adapt to long term abaria, but its much more likely that he _can_.

Even if man can't stand continuous abaria, it may not be necessary to spin the entire station. A centrifuge may be all that's needed. Just as periodic exercise can maintain muscle tonus, so periodic use of a centrifuge might eliminate abaraic deconditioning. Other devices such as elastic leg bands or lower body negative pressure boots may do the same job with less mechanical complexity.

In any case the alternatives and some of their charac-teristics are shown in Table I.

TABLE I

BIOMEDICAL "G" ALTERNATIVES

Alternative	Probable Need	Relative Confidence
Abaria with simple conditioning devices	Most Likely	Should avoid any deconditioning problems
Centrifuge	Intermediate	Should <u>solve</u> any deconditioning problems
Spinning-station	Least Likely	Will definitely solve deconditioning problems.

Engineering Requirements

There are currently no overriding engineering requirements for or against abaric operation. There are, however, some competing considerations:

1) Convenience. An artificial-g station makes astronaut adaption and training easier. Things like a dropped pencil or a plate of food behave in an earth bound fashion, and so do not require special training or engineering designs. Obviously for convenience in training and design an artificial-g station is better. This argument has a weak point--the station must be designed for abaric operation simply as a contingency. If the spinup mechanism fails, the subsystems and the crew must be able to operate in abaria either to fix the problem, to assess the damage, to await help, or to continue with a modified mission. So the zero-g design and training problem is still there, its just concealed as a contingency operating mode.

2) Efficiency. Limited testing to date has shown that man operates more efficiently in a g field than he does in abaria. While there is some question of his long term adaption to abaria, the data <u>does</u> indicate that you can get more work out of an astronaut if you don't leave him weightless. This means that there is a tradeoff between making the astronauts more

efficient and the added weight and complexity of
an artificial-g systems. Crudely speaking, we
may be able to do the same experiment load with
a smaller crew and a smaller station, simply by
adding the artificial-g capability.

One negative argument here is that many ex-
periments on a space station operate in zero gravity,
either because they must point at something station-
ary or because the lack of acceleration is an environ-
mental requirement for the experiment. This might be
solved in some cases by more complex experiments, for
example telescopes with slewing apparatus, but this
undoes some of the good by increasing the size and weight
of the experiments. It doesn't help to have an efficient
astronaut running an inefficient experiment. If we
put the experiments in a non-spinning counter-rotating
hub we lose astronaut efficiency right when we want
it most--when he's working on the experiments.

Clever designs may resolve most of these conflicts,
but the situation is currently far from clear. Be-
cause of this, artificial-g experiments have been pro-
posed, both on AAP and as part of the IOWS program, to
clarify some questions like:

1) How much less efficient _is_ an astronaut
    in abaria; and

2) Can simple accommodations be found for
    abaric experiments on a spinning station?

3) Habitability. Psychology, at best, is a qualitative
    field. When applied to a strikingly atypical popu-
    lation sample like a group of astronauts, the corre-
    lations are even less definitive. The lack of gravity
    might make it _easier_ for astronauts to stand the long
    confinement of a space **voyage**. On the other hand
    artificial gravity might be better. Still another
    approach may be to fly part of the voyage spinning and
    part of it in zero-g. And a still better alternative may
    be use a counter rotating hub and let the crewmen choose
    whichever environment they prefer at the moment. In
    any case the effects of gravity, or the lack of it,
    on the behavioral characteristics of the crew is a wide
    open question, and provides a strong motivation for
    conducting some artificial-g experiments.

4) Complexity. This has been argued in both directions.
    A spinning station is a gyroscope of sorts -- the
    angular momentum helps to make the station a more
    stable platform for optical observations. This means
    that the attitude control or pointing system can be
    less complex than a system for a static station. On
    the other hand the complexity of a counter-rotating
    hub must be added to the systems. And since an optical
    device can only view half the universe from one side
    of the counter-rotating hub, either two devices must
    be used, or a single device which could be moved from
    one end of the hub to the other must be designed. A
    third alternative is to despin the station, rotate the
    spin axis, and then spin up again. Any of these three
    alternatives can add cost or complexity.

        Although there is far from unanimous agreement
    on this subject, the consensus seems to be that the
    design problems for a spinning station are more com-
    plex than for a static station.

Programatic Considerations

        The general conclusions from these arguments are

1) we do not yet know if artificial gravity is a
    necessity or a luxury for long term space flights.

2) an artificial-g experiment would yield data on
    habitability and crew operations that might be
    helpful in future space station designs.

        In planning a space station program, these questions
lead to several interesting alternatives.

1) Assume that zero-gravity operations will be accept-
    able, and checkout the assumptions on an early flight.
    If they are correct continue abarically. If they are
    not, stop the program, develop a counter-rotating
    hub artificial gravity adaptor kit, and continue the
    program with a spinning space station.

2) Conduct some precursor flights to see if abaric
    operation is acceptable--at least for a reasonable
    crew rotation period like 90 days. If abaria is
    OK, design an abaric station. If it's not design
    a spinning station with a counter-rotating hub. Of
    course, the space station development effort must
    be postponed until the artificial gravity decision
    is made.

3) Assume that artificial gravity is required but design the station so that the counter-rotating hub and artificial gravity system may be used or left out. On the first flights, check the need for artificial gravity. If it's <u>not</u> needed, discard artificial-g hardware or use <u>it</u> on a subsequent experiment to test the psychological and psysiological effects of a spinning space station.

In each of these 3 approaches, abaria may or may not ultimately prove to be acceptable and the cost of the program will depend on the result.

Rough estimates of program cost and schedule for each of the three alternatives are shown in Table II and Table III. These tables use the following assumptions.

a) To develop a counter rotating hub and artificial-g adapter kit would cost about 100 million dollars and take 2 years to first launch. During those 2 years the program spending rate would be about 0.5 billion per year, of which about half would be wasted keeping design and manufacturing crews together, or in moth-balling new stations rolling off the assembly lines. The unit cost of an artificial- kit would be about 15 million.

b) The precursor experiment would be to fly an AAP wet workshop for about 120 days. If we use the backup workshop for this the only penalty is a one to two year delay in first flight of the space station. The cost penalty associated with this is 200 million for an additional S-IB/CSM launch, plus backup hardware.

c) The basic cost of the space station module is 600 million for development and about 100 million for a single man-rating flight.

The cost comparison shows that the cheapest program is to assume that abaric operation is acceptable and to be right. If you are wrong however, the program is the <u>most</u> expensive.

The cost of conducting precursor experiments is higher than the cost of designing the spinning capability in from the beginning. Consequently the next cheapest program is to design

TABLE II – PROGRAM ALTERNATIVES

FINAL RESULTS

PROGRAM "G" OPTION	ART-G REQ'D		ABARIA OK	
1) • No precursor experiments • Assume abaria OK • Use first flights of EOSL[1] as test for abaria. • If abaria OK--proceed • If necessary, program stops for artificial-g DDT & E.	Module Dev.Cost 600M Flt Test 215M 2 yr. Mark Time Penalty 600M ‾‾‾‾‾‾ 1,415M	Avail. Early 78	Module Dev.Cost 600M Flt Test 100M ‾‾‾‾‾‾ 700M	Avail. MID 75
2) • Precursor experiments to determine need for art.-g. • Select design based on experiment results. • Commiting program decision delayed until abaria question answered. (1-3 yr delay)	Module Dev.Cost 600M Precursor Flights 200M Art-g Dev. Cost 100M Flt Test 115M ‾‾‾‾‾‾ 1,015M	Avail. LATE 77	Module Dev.Cost 600M Precursor Flights 200M Flt Tests 100M ‾‾‾‾‾‾ 900M	Avail. LATE 77
3) • No precursor experiments • Develop artificial-g hardware. Use first flights of EOSL to determine need. • If hardware not needed discard or use for experiments. • If needed use available hardware.	Module Dev. Cost 600M Art-g Dev. Cost 100M Flt Tests 215M ‾‾‾‾‾‾ 915M	Avail. LATE 76	Module Dev.Cost 600M Art-g Dev. Cost 100M Flt Test 100M ‾‾‾‾‾‾ 800M	Avail. MID 75

[1]Earth Orbiting Space Lab

TABLE III ALTERNATIVE SCHEDULES

AAP		69	70	71	72	73	74	75	76	77	78
28 DAY MISSION	WS			△	△						
	CSM			△	△						
					↳BACKUP WORKSHOP						
56 DAY MISSION	CSM			▲							
56 DAY MISSION	ATM				△						
	CSM				▲						
ALTERNATIVES #1 ABARIA OK	ψ B	6MO ▢									
	ψ C		18MO ▭								
	ψ D			42MO ▭				△▲			
#1 ART-G REQ'D	ψ B	▢ 6MO									
	ψ C		18MO ▭								
	ψ D			42MO ▭			△▲				
G-KIT DEV.									18MO ▭	△▲	
#2 ABARIA OK AND ART-G REQ'D 120D AAP EXT.	WS				△						
	CSM				▲ ▲						
	ψ B			6MO ▢							
	ψ C				18MO ▭						
	ψ C					42MO ▭			△▲		
#3 ABARIA OK	ψ B	▢ 6MO									
	ψ C		18MO ▭								
	ψ D			42MO ▭			△ ▲				
#3 ART-G REQ'D	ψ B	▢ 6MO									
	ψ C		18MO ▭								
	ψ D			42MO ▭			△ ▲			
ART-G FLT.								△▲			

NOTE:
▲ MANNED
△ UNMANNED

for artificial-g and test to see if you need it with the first flights. The difference between this and cheapest program is 100 to 200 million dollars. That does not seem unreasonable as the cost of an insurance policy on a 3 to 4 billion dollar program. And as a fringe benefit, the hardware can be used for subsequent artificial-g experiments if funds permit. The use of precursor flights doesn't seem to save any money, and what's worse, the funding in the early years of the program isn't reduced because the cost of the precursor flights fill the gap that's left when the main program is postponed. So the use of a precursor program seems to have little to recommend it.

Conclusion

The principal conclusion from these considerations is that an attractive approach is to require that the space station be designed for both abaric and artificial-g operation. The design and development effort should include a module which is a counter-rotating hub, and an artificial-g system that may be included in the program on the second or third flights. As a consequence, Phase B studies should evaluate the schedule and cost impact of including such an effort in Phases C and D. A firm decision to include the artificial-g kit in the program should await the results of the Phase B study.

E. D. Marion

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